TECHNICAL BASIS FOR THE ARTICLE IN SEPTEMBER USA TODAY MAGIZINE

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How Much Weapons-Grade Plutonium could North Korea Have?

Nuclear weapons use either uranium or plutonium. Uranium as it comes out of the rocks containing it is unsuitable for weapons use and must be "enriched". Natural uranium is composed of two different isotopes and it is the lighter one, comprising only 0.7% of the natural metal that must be separated for weapons use. This is what the centrifuges one hears so much about are used for. But simple uranium weapons are heavy and not suitable for ICBMs whose range depends on the weight of the warhead. It is plutonium, which must be produced in nuclear reactors from uranium that is of interest for an ICBM program.

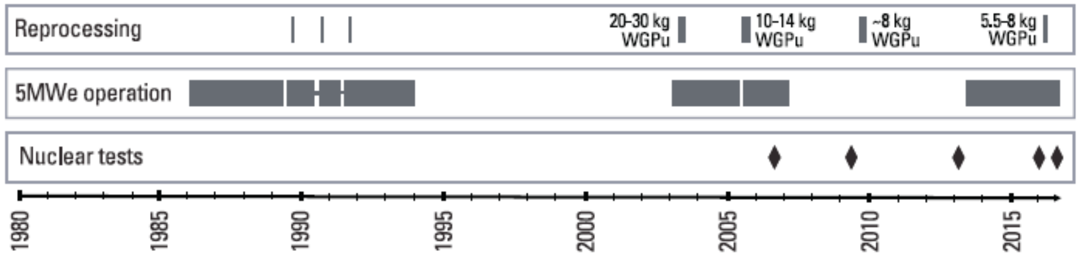
There are two types of plutonium of importance that are produced in nuclear reactors called "weapons grade" and "reactor grade". Weapons grade has a low amount of the heavier isotopes of plutonium; the concentration of which increases the longer the uranium used to produce the plutonium remains in the nuclear reactor. To produce good quality weapons-grade plutonium, with a concentration of the most important heavy isotope (Pu240) less than 8%, one uses a short "burnup" fuel cycle. Meaning that the reactor fuel rods are removed earlier than they would be if the reactor was used to produce electricity.

The problem with the heavier isotope Pu240 is that it spontaneously emits neutrons that can cause a nuclear weapon to "pre-detonate". Nuclear weapons use high explosive to compress the plutonium to achieve a "critical mass". If a neutron sets off the chain reaction in the plutonium before it is maximally compressed this is called pre-detonation. This can greatly reduce the yield (size) of the nuclear explosion.

What we need to know is how much weapons grade plutonium the North Koreans could have produced and how much weapons grade they can produce. This in turn depends on the number of *operational* nuclear reactors they have. As of 2015, so far as we know, they have only one small reactor estimated to have a power of 25 megawatts-thermal (MWt) at the Yongbyon Nuclear Research Center north of Pyongyang. This reactor is fueled with unenriched, natural uranium using a graphite moderator rather than the heavy water used in other reactors that use natural uranium for fuel. Pure graphite is often used as a moderator in "production reactors" intended for use in a weapons program. The number given for the reactor thermal power will be important for estimating weapons grade plutonium production.

The history of this reactor is somewhat murky. Perhaps the best way of displaying its operational history, and estimates of weapons grade plutonium produced, can be found in the article *North Korea's Stockpiles of Fissile Material* by Siegfried Hecker, Chaim Braun and Chris Lawrence published in 2016 in the journal *Korea Observer*. The timeline below comes from this article. Note that the entry 20-30 kg WGPu (20-30 kilograms of weapons grade plutonium) in the first row is for the period from1986 to 2003.

There is some uncertainty about the period from 1986-1994 during which the reactor may have used a longer burnup cycle than optimal for producing weapons grade plutonium. The resulting plutonium would have a degraded yield if used in weapons. This may be a possible explanation for the low yield of North Korea's first two or three nuclear weapon tests. Because of the heat generated by this type of plutonium, the high explosive design used in the test would have had to be modified to remove the heat generated—otherwise the high explosive would melt and decompose—but such modifications would have been within North Korea capability at the time. But this uncertainty in the amount of weapons grade plutonium produced since 1986 will not affect any future policy considerations.



In order to get an estimate of the maximum amount of weapons grade plutonium that could have been produced, the authors of the *Korea Observer* article assumed that during the period of operation from 1986-1994 the reactor was run so as to optimize the plutonium for weapons. This means that the fuel would be reprocessed after two or three years in the reactor. The estimates above give a total of 42-60 kilograms of weapons grade plutonium. If the amount of plutonium used in the 5 nuclear tests is subtracted, and it is assumed that each test required about 4 kilograms (see below), North Korea would have some 22-40 kilograms left in its stockpile as of 2017, consistent with the claim of the authors.

Another estimate of the amount of weapons grade plutonium produced by the reactor can be obtained from data given in a report written by a contractor for the U.S. arms Control and Disarmament Agency in 1980 titled "Criticality Studies of Graphite Moderated Production Reactors". Given the data in this report, the fact that the reactor is rated at 25MWt, and knowing its initial fuel load of natural uranium, generally assumed to be 45 metric tons, one can calculate the weapons grade plutonium production rate as 22.5 kg/3yr assuming uninterrupted operation over the full 3-year period. If the "capacity factor" (the fraction of the year that the reactor actually operated) is reduced to the more probable value of 70% the production would be reduced to 15.75 kg/3yr.

It is thought that the period from 1986-89 the reactor produced little if any weapons grade plutonium so that the period from1989-94 can be considered as two 3-year exposures of different loads of fuel. The total produced from 1989-94 would then be 31.5 kg, essentially consistent with the table given above. The period from 2004-2007 also gives consistent results, but agreement is not as good between 2013-2017 because of the lack of adequate data about the reactor's shut downs due to cooling problems. All in all, the numbers in the table above are an adequate basis for what follows.

How Many Bombs?

The amount of weapons grade plutonium needed for a bomb depends on the design of the weapon. The amount contained in the so called "Fat Man" weapon used by the United States in the WW-II bombing of Nagasaki was about 6 kilograms. But such weapons would not be suitable for ICBMs. The US weapon weighed 4670 kilograms (10,000 pounds). A more sophisticated design using what is called a levitated pit could perhaps double the explosive yield of the weapon but not significantly decrease the weight. Even with somewhat more sophisticated designs it is doubtful that North Korea could reduce the amount of weapons grade plutonium needed for each weapon much below 5 kg. The argument made in the press and elsewhere that they could have used only 2 kilograms in some of the low yield tests is apt to be wrong.

The configuration used in modern weapons is probably beyond North Korea's capability for many years. It is, however, possible that extensive high explosive testing could reduce the weight of the designs available to them within perhaps a decade or less. Unless North Korea completes work on a larger 100 MWt reactor, which was not the case as of 2015, they would be limited to producing a maximum of enough weapons grade plutonium for one bomb per year using these early designs.

Should North Korea be able to reduce the amount of high explosive needed for the weapon so as to reduce its diameter to say about half a meter, the weight could be as low as 80 kg, which could be adequate for their current ICBM design. If the 2016 photo showing Kim Jong-un with his nuclear warhead mock-up perhaps a meter in diameter is anything more than a publicity stunt, there isn't much time left.

Nuclear Tests

North Korea has carried out five nuclear tests as of 2017. The yield for each of the tests was (in terms of kilotons of TNT): (1) 9 October 2006-less than one kiloton; (2) 25 May

2009-about 4 kilotons; (3) 12 February 2013-about 6-7 kilotons; (4) 6 January 2016-about 7-10 kilotons; (5) 9 September 2016-about 12-24 kilotons. Note that the yield goes up with time probably reflecting their increasing ability to effectively configure the high explosives used in the weapon tests. The modern way to design the high explosive configurations uses equipment unlikely to be available to North Korea. As discussed above, had each of these tests used 5 kilograms of weapons grade plutonium North Korea would only have about 22-40 kilograms left. This represents enough for 4-8 nuclear weapons.